III. "Researches in Animal Electricity." By Charles Bland Radcliffe, M.D. Communicated by C. Brooke, F.R.S. Received, Part I., Feb. 18; Part II.-V., March 11, 1869.

(Abstract.)

After a description of certain instruments, now employed for the first time in researches of this kind, the topics inquired into successively are:—the electrical phenomena which belong to nerve and muscle in a state of rest; the electrical phenomena which mark the passing of nerve and muscle from the state of rest into that of action; the motor phenomena ascribed to the action of the "inverse" and "direct" voltaic currents; and electrotonus.

I. *On certain Instruments now employed for the first time in Researches in Animal Electricity.*

The instruments here referred to and described are Sir Wm. Thomson's Reflecting Galvanometer, Mr. Latimer Clarke's Potentiometer, and some new electrodes devised by the author.

Sir Wm. Thomson's Reflecting Galvanometer, which is the principal galvanometer made use of, is stated to be more manageable than the old galvanometer of Prof. Du Bois Reymond, and not less sensitive.

Mr. Latimer Clarke's "Potentiometer," which is really a very ingenious adaptation of the idea upon which the Wheatstone's Bridge is based, is the instrument employed for the measurement of tension. It is so delicate as to measure with certainty the $\frac{1}{10,000}$ part of the tension of a Daniell's cell.

The new electrodes are simply pieces of platinum wire, flattened and pointed at the free ends, and having these free ends freshly tipped with sculptor's clay at the time of an experiment. The necessary homogeneity of the two is secured by pushing the clay a little further on one of the wires, or by pulling it a little further off; for by a simple manipulation of this kind it is found that the clay tips of the two electrodes may be so adjusted as to allow them to be brought together without the development of the slightest current. After a very little practice it is found, indeed, that in a very few moments the two electrodes may be made perfectly homogeneous by thus covering or uncovering one of them. And, further, it is found that the secondary polarization arising from the passage of a current may be got rid of at once by simply bringing the clay tips of the two electrodes together so as exclude the polarizing current from the circuit of the galvanometer, and by leaving them in this position for a moment or two—by *short-circuiting* the galvanometer, that is to say, for a very brief period. It is found, in short, that these electrodes are infinitely more manageable, and not less effectual, than the electrodes commonly in use, in which enter zinc troughs filled with saturated solution of zinc, and pads of blotting-paper, the pads being kept sodden with this

solution by having one of their ends dipping into it—electrodes which, to say the least, are not easily put in order or kept in order.

II. *On the Electrical Phenomena which belong to Living Nerve and Muscle during the state of rest.*

Living nerve and muscle supply currents to the galvanometer (the *nerve-current*, and the *muscular current*, so called) which are not supplied by dead nerve and muscle. These currents, when the tissues supplying them are fresh and at rest, show that the surface composed of the sides of the fibres, and the surface composed of the ends of the fibres, are in opposite electrical conditions, the former surface being positive, the latter negative. These currents, when the tissues supplying them are about to die, and, in some cases, when they are put in action, are wholly or partially reversed—are so changed in direction, that is to say, as to show that there is at this time a total or partial reversal in the electrical relations of the ends and sides of the fibres. The fact of a *partial* reversal, in which the fibres may be positive in some part of their sides and negative in others, or positive at one of their ends and negative at the other, is now pointed out for the first time.

Nerve and muscle, and the animal tissues generally, oppose a very high resistance to the passage of a common voltaic current—so high, indeed, as to justify the inference that muscles and nerves may be looked upon as non-conductors rather than as conductors. The resistance in an inch of the sciatic nerve of a frog, for example, is about 40,000 B.A. units, or nearly seven times that of the whole Atlantic Cable.

The mean tension of the nerve-current and the muscular current proves to be about half that of a Daniell's cell. Moreover, negative and positive electricity, in equal amounts, are both found to be present. The case is not one in which only one kind of electricity is present,—in which what appears to be negative is only a lower degree of positive, or *vice versâ*; it is one in which two electricities are present, one above the zero of the earth, the other below it—one as much above the zero of the earth as the other is below it. These facts are made out by means of the potentiometer.

Looking at these facts, and especially at the comparative non-conductibility of nerve and muscle, wholly or in part, and at the presence in these tissues of positive and negative electricity in equal quantities, it is thought probable—

That the comparative non-conductibility of nerve and muscle may allow certain parts of these tissues to act as *dielectrics* rather than as conductors, and that these parts may be the sheaths of the fibres.

That the development of one kind of electricity (by oxygenation, or in some other way) on the exterior of the sheaths of the nerve and muscular fibres may lead, *by induction,* to the development of the other kind of electricity on the interior of these sheaths.

That the exterior and interior of the sheaths of the fibres in nerve and muscle may be in opposite electrical conditions, because the sheath plays the part of a dielectric.

That the surface composed of the ends of the fibres in nerve and muscle may be in an electrical condition opposed to that of the surface composed of the sides of these fibres, because there may be a communication at the ends of the fibres with the interior of the sheaths of the fibres.

That the nerve-current and muscular current may be no more than accidental phenomena, depending upon the mere fact of the positive exterior and the negative interior of the nerve and muscular fibre being connected by a conductor.

That the fundamental electrical condition of nerve and muscle *during rest* may be, not one of currents ever circulating in closed circuits around *peripolar* molecules, of which currents the nerve-current and the muscular current are only derived portions, but one of tension—a condition, not current in any sense, but static—a state which, as long as it lasts, must tend to keep the molecules acted upon in a state of mutual repulsion.

III. *On the Electrical Phenomena which mark the passing of Nerve and Muscle from the state of Rest into that of Action.*

The fact of "induced contraction" so called, together with the analogies existing between the muscles and the electric organ of the torpedo as to the relation to the nervous system and the manner of acting in more cases than one, are cited as reasons for believing, with Matteucci, that a discharge, analogous to that of the torpedo, marks the passage of both muscle and nerve from the state of rest into that of action.

And, further, the fact, well established by Prof. Du Bois Reymond, that the nerve-current and the muscular current are both alike greatly *weakened* when the nerve or muscle passes from the state of rest into that of action, is cited as corroborative evidence in support of Matteucci's conclusion—as demonstrating, in short, the actual disappearance of electricity in the very cases in which Matteucci, from analogy solely, infers the existence of *discharge.*

Again, the conclusion arrived at as to the electrical condition of muscle and nerve during the state of rest, is looked upon as another argument to the same effect; for if it be true that this condition is one, not of current, but of *charge*, then there is a substantial ground for supposing that the passing of nerve and muscle from the state of rest into that of action may be marked by *discharge.*

In a word, the more the evidence is considered the more it seems to justify this conclusion,—that the passing of nerve and muscle from the state of rest into that of action is marked by a discharge of electricity analogous to that of the torpedo.

IV. *On the Motor Phenomena ascribed to the action of the "Inverse and Direct" Voltaic Currents.*

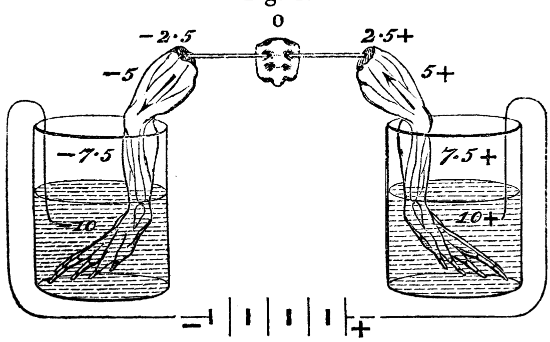
When a voltaic current is so made to pass through the two hind limbs of a prepared frog that the current is "inverse" in one limb and "direct" in the other, it is found that the closing and opening of the circuit may or may not be attended by contraction, and that the presence or absence of contraction may or may not obey a similar rule in the two limbs. The facts admit of being arranged in three stages, thus:—

		The limb in which the current is "Direct."		The limb in which the current is "Inverse."	
		On closing circuit.	On opening circuit.	On closing circuit.	On opening circuit.
Stage I. When the electricity acts *similarly* upon the two limbs.	(*a*) With a *weak* battery.	Contraction.	0.	Contraction.	0.
	(*b*) With a *strong* battery.	Contraction.	Contraction.	Contraction.	Contraction.
Stage II. When the electricity acts *differently* upon the two limbs.	1st period.	Contraction.	0.	Contraction.	Contraction.
	2nd period.	Contraction.	0.	0.	Contraction.
	3rd period.	0.	0.	0.	Contraction.
Stage III. When the electricity is again made to act similarly upon the two limbs by reversing the position of the poles.	(*a*) With a *weak* battery.	Contraction.	0.	Contraction.	0.
	(*b*) With a *strong* battery.	Contraction.	Contraction.	Contraction.	Contraction.

In seeking to account for these facts, the "direct" and "inverse" currents are not the only agencies which have to be taken into consideration. If the limbs were perfectly sufficient conductors, the sole agencies at work might be these currents; but instead of being very good conductors, the limbs are, in fact, non-conductors rather than conductors, opposing a resistance to the current of about 40,000 B.A. units (a resistance nearly seven times that of the whole Atlantic Cable); and the result of closing the circuit with them is this—that each limb is found to be charged with the free electricity which is present at the poles when the circuit is open, and which would be entirely discharged if the place of the limbs were supplied by a perfectly sufficient conductor. The case is one in which, in accordance with the investigations of Mr. Latimer Clarke on the tension of the voltaic circuit, each limb is found to participate in the charge of the pole nearest to it, the charge being positive in the limb in which the current is inverse, and negative in the limb in which the current is direct, the tension of the charge in each limb diminishing regularly from the pole where it is highest, to some point midway between the poles, where it is at zero; the

case is one in which, supposing the value of the tension at each of the poles to be 10, the state as to tension at different points between the poles is found to be that which is indicated by the figures in the accompanying sketch :—

Fig. 1.



This, then, being the state of the limbs as to tension under these circumstances, it is plain that there must be definite changes in tension at the closing and opening of the circuit. It is plain that the limbs must be traversed by a discharge at the moment of closing the circuit; for the charge of the poles must diminish in direct proportion to the freedom with which the current passes. It is plain also that the opposite electricities which are accumulated in the limbs while the circuit is closed must be discharged when the circuit is opened. It is possible also that the discharge at the opening of the circuit may be *less* in amount than that which occurs at the closing of the circuit; for immediately after the opening both the limbs may be supposed to receive a charge from the pole with which they happen to remain in connexion, which charge will to some degree counteract the discharge.

How then? Is it possible that these changes of tension may have to do with the motor phenomena which are ascribed to the action of the direct and inverse currents?

That the changes of tension in question are of themselves sufficient to tell upon the muscles in the requisite manner is proved by a new and very curious experiment. The two hind legs of a frog, prepared and arranged as in the experiment for exhibiting the action of the inverse and direct currents, are connected, time after time, first with one pole of the battery and then with the other, but never with the two poles at once. The result, for a time at least, is contraction in one or both of the limbs when they are thus carried from one pole to the other. There is a succession of charges and discharges; for before a charge can be received from either pole this charge must neutralize the charge carried away from the other pole. The contraction must have to do with changes of tension, and with changes of tension only; for the circuit remains open from the beginning to the end of

the experiment. The case, indeed, appears to be not remotely analogous to that in which the prepared limbs of a frog are made to hang from the prime conductor of an electrical machine, and then charged and discharged alternately; for here the rule as to contraction is the same, namely this,—that the limbs contract, not when they receive or while they retain the charge, but at the moment of discharge.

That the changes of tension in question *do* actually affect the limbs as they are found to be affected under the action of the inverse and direct current appears to gain in probability as the matter is more fully inquired into.

There is no difficulty in referring to changes of tension the phenomena belonging to the first stage (*vide* Table). If the closing and opening of the circuit be attended by discharge, and if contraction be coincident, not with charge but with discharge, the presence of contraction in both limbs at the moments of opening and closing the circuit is in accordance with rule; and if the discharge at the opening of the circuit be weaker than that which happens at the closing, it is easy to see that with a weak battery the stronger discharge at the moment of closing the circuit may be strong enough to tell upon the muscles when the weaker discharge at the opening of the circuit is not strong enough to do so. Indeed it is plain that the absence of contraction at the opening of the circuit in the case where a weak battery is used is merely a matter of wanting battery power, for the missing contraction is made to appear by simply supplying this want.

Nor is there any difficulty in applying the same key to the explanation of the phenomena belonging to the second stage (*vide* Table).

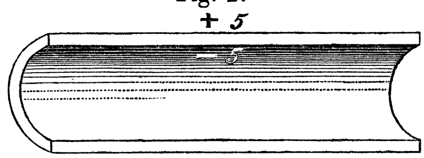
It is a fact that the power of contracting is affected very differently in the two limbs by the action of the electricity. The limb in which the current is direct loses this power much more speedily than it does when left to itself; the limb in which the current is inverse retains this power much longer than it does when left to itself; the limb in which a direct current has been passed until the power of contracting is at an end recovers this power, and this, too, more than once, if the direction of the current be changed for a time. Of these facts—the impairment of the power of contracting in the limb in which the current is direct, the preservation and restoration of this power in the limb in which the current is inverse—there can be no question.

There is also reason to believe that there are electrical differences in the two limbs which will, in some degree at least, account for the differences in the power of contracting, and for other differences which have yet to be considered.

The conclusion already arrived at respecting the natural electricity of nerve and muscle is that the state during rest is one of charge—that, ordinarily at least, the sheaths of the fibres are charged positively at their exterior and negatively at their interior. The resistance of the animal tissues to electrical conducion, it is assumed, is sufficient to keep the two

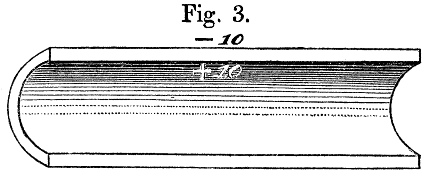
opposite electricities apart—an assumption, be it remarked, which is not a little borne out by the fact that the resistance which the voltaic current encounters in the hind limbs of a frog when its course is up one limb and down the other (*vide* fig. 1) is sufficient to keep the two limbs in opposite electrical conditions as regards charge. In short, the natural electrical condition of nerve and muscle during rest may be assumed to be one in which the exterior of the sheath of the fibre is positive and the interior negative—a state of charge which, taking 5 as the value of the tension, and viewing the sheath in longitudinal section from within, may be figured thus :—

Fig. 2.



The electrical condition of the fibres of the nerves and muscles of the *limb in which the current is direct* may be assumed to be one in which the exteriors of the sheaths are charged negatively from the negative pole, and the interiors positively by induction—a state in which the disposition of the two electricities forming the charge is the reverse of that which belongs to the natural charge—in which, before this reversal can take place, there must be a meeting of opposite electricities without and within the sheaths which must result in the discharge of the weaker natural charge and of an equivalent quantity of the artificial charge—which, assuming 10 as the value of the tension, and taking the figure already used to illustrate the state of things in the natural charge, may be represented thus :—

Fig. 3.

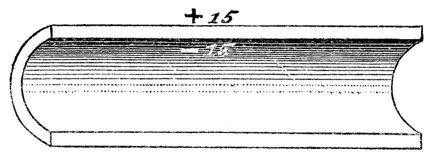


The case, indeed, is one in which the artificial charge of the fibres involves a *reversal* similar to that which happens naturally when these fibres, in some instances at least, have lost a great portion of their activity,—in which there may be supposed to be a similar reason, whatever that may be, for failure in this activity : and hence it need not be altogether a matter of wonder that the limb in which the current is direct should lose its power of contracting more rapidly than the same limb when left to itself.

The electrical condition of the fibres of the nerves and muscles of the *limb in which the current is inverse,* on the other hand, may be taken as one in which the exteriors of the sheaths are charged positively from the positive pole, and the interiors negatively by induction—a state in which

the sheaths are affected without and within similarly by the natural and artificial charges—in which the artificial may be added to the natural charge, causing, not discharge, as in the case of the limb in which the current is direct, but *surcharge*—in which, assuming the value of tension to be 10 for the artificial and 5 for the natural charge, and taking the figure used before in illustration, the result of this combination of charges may be set down thus:—

Fig. 4.



The case is one in which the artificial charge, by supplementing the natural charge, may be supposed to retard the disappearance of the natural charge, and with it the power of contracting; for between this charge and this power there is, without question, a connexion which may not be severed. And if this be so, then it is not difficult to advance a step further and perceive how it is that this artificial charge may restore the natural power of contracting after it is lost, and how, in this way, after this power has disappeared from the limb in which the current is direct, it may be brought back again by reversing the position of the poles. In a word, it is not altogether unintelligible that there should be along with the inverse current an action which preserves and restores the power of contracting.

And if the condition of the two limbs be thus different when the circuit is closed, a clue is found, by tracing which it is possible to arrive at an explanation of the different behaviour of the two limbs at the moment of closing and opening the circuit.

In the second period of the second stage (*vide* Table), the limb in which the current is direct contracts at the moment of closing and not at the moment of opening the circuit, and, contrariwise, the limb in which the current is inverse contracts at the moment of opening the circuit and not at the moment of closing it; and most assuredly there is nothing anomalous in these differences.

In the *limb in which the current is direct*, as will appear on comparing the two figures 2 & 3, there must be at the moment of closing the circuit a conflict between the natural and artificial charges of the fibres before the stronger artificial charge can have the victory which it gains in the end,—a conflict in which the neutralization of the natural charge by an equivalent quantity of the artificial charge, must issue in discharge; and hence the presence of contraction at this moment, if contraction be coincident, not with charge, but with discharge. Indeed there is a double reason for contraction at this moment; for in addition to

this discharge is the discharge of the opposite electricities of the poles which attends upon the closing of the circuit in any case. Nor is the absence of contraction at the opening of the circuit unintelligible; for it is easy to see that the loss in the power of contracting which the limb in which the current is direct has experinced by this time, may have rendered the limb incapable of responding to the weaker discharge which attends upon the opening of the circuit.

In the *limb in which the current is inverse,* as will appear on comparing the figures 2 & 4, there must be the addition of the artificial charge to the natural charge—a surcharge—a state which may nullify the discharge attending upon the closing of the circuit; and hence the absence of contraction at the closing of the circuit; for, according to the premises, there will be no contraction if there be no discharge, or, rather, there will be no contraction if there be no *sufficient* discharge. Nor is a reason wanting for the presence of contraction at the opening of the circuit in this case; for if the action of the electricity be to preserve and restore the power of contracting in the limb in which the current is inverse, it is easy to suppose that in the case in question this power is so far preserved as to allow the limb to respond to the discharge which attends upon the opening of the circuit.

Nor need there be any difficulty in dealing with the phenomena belonging to the other periods of the second stage. The presence of contraction at the closing as well as at the opening of the circuit, in the case of the limb in which the current is inverse (second stage, first period, in Table), would seem to imply no more than this, that the conditions present in the first stage have not yet come to an end. The absence of contraction at the closing as well as at the opening of the circuit in the limb in which the current is direct (second stage, third period, in Table), may merely be due to the electricity having now so far destroyed the power of contracting as to make the limb incapable of responding to the stronger no less than to the weaker of the discharges acting upon it. The differences in question are merely transitional, nothing more.

A few words will suffice for all that need be said respecting the phenomena which remain to be considered (third stage in Table). For if the charges of the poles play the part which has been ascribed to them, it is to be expected that, by reversing the position of the poles, what was done in either limb by either pole may be undone by the other pole, and that at a certain moment after this reversal the two limbs may be restored to that state of similarity in which they will, as at first, contract similarly on closing and opening the circuit, one or both—at the opening as well as at the closing if the battery power be strong, at the closing only if the battery power be feeble.

It would seem, then, as if the changes of tension, to which attention has been directed, supplied an explanation of the motor phenomena ascribed to the action of the "inverse" and "direct" currents, which, to say the least,

is more intelligible than any which can be found in the action of the currents themselves, and that in fact it is a gain rather than a loss to discard altogether the "inverse" and "direct" currents from the field of operation in which they have hitherto been supposed to play so all-important a part.

It would seem, in fact, that the evidence in this section agrees with that supplied in the two previous sections in leading to the conclusion that muscular relaxation is associated with a state of charge, and muscular contraction with a state of discharge. It would even seem as if all the evidence so far gave countenance to the conclusion that the state of charge may cause muscular relaxation by keeping the molecules of the muscle in a condition of mutual repulsion, and that the state of discharge may lead to muscular contraction by doing away with that state of electrical tension which prevents the molecules of the muscle from yielding to the attractive force, inherent in their physical constitution, which is ever striving to bring them together.

V. *On Electrotonus.*

It is not enough to be content with repeating, after Professor Du Bois Reymond, that the nerve-current and voltaic current are in the same direction in anelectrotonus and in opposite directions in cathelectrotonus, or, after Professor Eckhard, that the activity of the nerve is paralyzed in the former of these states and exalted in the latter. In fact, the subject of electrotonus requires complete revision.

The direction of the nerve-current and voltaic current is found to agree in anelectrotonus and to disagree in cathelectrotonus, if, as is commonly the case, the direction of the former current is from the end to the side of the fibres; but not so if, as may happen, the course of the nerve-current is the reverse of this. In this case the direction of the two currents will agree in cathelectrotonus and disagree in anelectrotonus. Nay, more, there are movements of the needle, corresponding perfectly to those which happen in the two electrotonic states, when the experiment is made upon dead nerve and upon other bodies too, provided these bodies are sufficiently bad conductors of electricity.

If a piece of wire be placed as the piece of nerve is placed in an experiment on electrotonus and dealt with in the same manner, the needle of the galvanometer remains motionless; and so likewise if a piece of cotton or hempen thread moistened with water be substituted for the wire; but not so if the nerve be represented by silk or gutta percha moistened with water. In the latter case, indeed, the needle is found to move as it moves in anelectrotonus and cathelectrotonus when the voltaic poles are placed in the way necessary to produce these two electrotonic conditions. The needle may be at zero before these movements are manifested, or it may not. It is at zero if the electrodes of the galvanometer are homogeneous; it is on this or that side of the zero-point if, as commonly happens,

there is some accidental heterogeneity in these electrodes. Still no serious complication in the problem is introduced by the presence of this purely accidental current; for all that it does is to shift in one direction or the other the point from which the electrotonic movements of the needle have to be reckoned. Be this accidental current present or absent, indeed, the degree and direction of the electrotonic movements of the needle remain the same, and it is only the starting-point of the movement which is shifted.

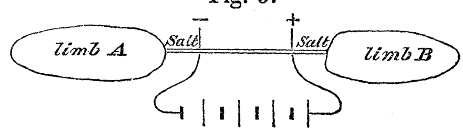
These, then, being the facts, it is difficult to regard the electrotonic phenomena in nerve which are exhibited in the galvanometer as modifications of the nerve-current. The nerve-current, if present, is undoubtedly modified, just as is the accidental current depending upon the heterogeneity of the electrodes of the galvanometer to which attention has just been directed; but the essential workings in electrotonus must be deeper than the nerve-current, deeper even than the nerve. It would seem, indeed, that the nerve-current must in reality play as accidental a part in the phenomena of electrotonus as does the current depending upon heterogeneity in the electrodes of the galvanometer in the experiment in which gutta percha or silk moistened with water is substituted for the nerve. It would seem, indeed, that a given degree of resistance between the voltaic poles is in reality all that is essential to the manifestation of the galvanometric phenomena of electrotonus—a resistance sufficient to pen up free positive electricity at the positive pole and free negative electricity at the negative pole; and that the movements of the needle may be owing to the outflowing or inflowing of this free electricity through the coil of the galvanometer from or to the pole which happens to be nearest to the coil; *for it is found that similar movements to those which happen in electrotonus are witnessed when the part of the nerve acted upon ordinarily by the voltaic current is charged alternately with positive and negative electricity from a friction-machine.* In an experiment on electrotonus, as commonly conducted, the insulation of the circuits of the galvanometer and the battery is sufficient to prevent any passage of the voltaic current proper into the coil, but it is not sufficient to hem in electricity of a higher tension; it is not sufficient to prevent the flowing of a stream of free electricity *from* the positive pole, and *to* the negative pole, of which stream a *part* may pass through the coil of the galvanometer, and so act upon the needle. And hence the movements of the needle of the galvanometer in anelectrotonus and cathelectrotonus; for the movement in anelectrotonus is only that which happens when free positive electricity is passed through the coil, and the movement in cathelectrotonus is only that which happens when free negative electricity is so passed.

Instead of the activity of nerve being paralyzed in anelectrotonus and exalted in cathelectrotonus, a very different conclusion appears to be necessary. Taking the prepared limbs of a frog, and placing the middle portion of the connecting band of nerve belonging to them across the poles of a voltaic battery of which the circuit is open, a drop of salt water is ap-

plied on each side to the portion of nerve beyond the pole. Then, having waited until the salt has set up a state of tetanus in both limbs, the voltaic circuit is closed and opened in turn, with the poles first in one position and then in the other. On closing the circuit, anelectrotonus is set up on the side of the positive pole, cathelectrotonus on the side of the negative pole; and what has to be done is to notice the behaviour of the limb before, during, and after the setting up of these states. In this experiment are four steps, of which the particulars may be tabulated thus:—

Step 1. Poles arranged so as to cause cathelectrotonus in limb A, anelectrotonus in limb B.

Fig. 5.



Cathelectrotonus on the side of limb A.	Action of salt, causing in limb A	Anelectrotonus on the side of limb B.	Action of salt, causing in limb B
Before.	Tetanus.	*Before.*	Tetanus.
During.	0.	*During.*	0.
After.	Momentary contraction.	*After.*	Tetanus.

Step 2. Poles transposed so as to cause anelectrotonus in limb A, cathelectrotonus in limb B.

Limb A + —Limb B

Anelectrotonus after Cathelectrotonus on the side of limb A.	Action of salt, causing in limb A	Cathelectrotonus after Anelectrotonus on the side of limb B.	Action of salt, causing in limb B
During.	Rest at first, then twitchings, progressively increasing in frequency and force	*During.*	Semi-tetanus at first, then rest.
After.	Tetanus.	*After.*	Momentary contraction.

Step 3. Poles arranged as at first, so as to cause cathelectrotonus in limb A, anelectrotonus in limb B.

Limb A— +Limb B

Cathelectrotonus after Anelectrotonus on the side of limb A.	Action of salt, causing in limb A	Anelectrotonus after Cathelectrotonus on the side of limb B.	Action of salt, causing in limb B
During.	Semi-tetanus at first, then rest.	*During.*	Rest at first, then twitchings, progressively increasing in frequency and force.
After.	0.	*After.*	Tetanus.

Step 4. Poles transposed again, so as to cause anelectrotonus in limb A, cathelectrotonus in limb B.

Limb A+ —Limb B

Anelectrotonus after Cathelectrotonus on the side of limb A.	Action of salt, causing in limb A	Cathelectrotanus after Anelectrotonus on the side of limb B.	Action of salt, causing in limb B
During.	Rest at first, then twitchings, progressively increasing in frequency and force.	*During.*	Semi-tetanus at first, then rest.
After.	Semi-tetanus.	*After.*	0.

In order to explain this experiment, all that is necessary is to realize the fact (for fact it is) that anelectrotonus has to do with a charge from the positive pole, and cathelectrotonus with a charge from the negative pole, and to suppose that these charges react with the natural charge of the animal tissues precisely as they do in the case of the limbs in which inverse and direct currents are passing—in similar cases, that is to say; for, *as regards the phenomena of tension,* the state in anelectrotonus is identical with that which is present in the limb in which the current is inverse (see fig. 4), and in cathelectrotonus with that which is present in the limb in which the current is direct (see fig. 3).

In the first stage of the experiment the facts are—suspension of the tetanus caused by the salt during cathelectrotonus and anelectrotonus alike, return of tetanus after anelectrotonus, momentary contraction only after cathelectrotonus; and these facts are not inexplicable. The tetanus after anelectrotonus, and the momentary contraction only after cathelectrotonus, show, as it would seem, that the power of responding to the action of the salt has been preserved in anelectrotonus, as in the case of the limb in which the current is inverse, and lost in cathelectrotonus, as in the case of the limb in which the current is direct. It is quite intelligible also that the tetanus caused by the salt should be suspended during the continuance of the electrotonic state, if this state be based upon charge, and if this charge have that power of counteracting contraction which would seem to belong to it.

In the other steps of the experiment the two topics which have to be considered are (1) what happens when anelectrotonus follows cathelectrotonus, and (2) what happens when cathelectrotonus follows anelectrotonus.

In the case in which anelectrotonus follows cathelectrotonus the facts are these:—during anelectrotonus, rest at first, then twichings progressively increasing in frequency and force; and after anelectrotonus, tetanus; and so it should be. If, indeed, the power of contracting is impaired in cathelectrotonus and preserved in anelectrotonus, it may be supposed, when anelectrotonus is made to follow cathelectrotonus, that the power of contracting has been so far impaired by the previous state of cathelectrotonus as to oblige the muscles to remain in a state of rest until this power is to a certain degree restored by the state of anelectrotonus; and that the rest at first, and the twitchings progressively increasing in force and frequency afterwards, when anelectrotonus is made to follow cathelectrotonus, may be accounted for in this way. Moreover the tetanus upon the cessation of anelectrotonus may be supposed to receive its explanation also, if the action of the anelectrotonus has been to preserve and restore the power of contraction, and if the state of charge upon which that of anelectrotonus is based, has, in some degree at least, the effect of counteracting contraction.

In the case of cathelectrotonus after anelectrotonus, also, what happens is intelligible enough when the same principles of interpretation are applied to the facts. The facts themselves are these:—during cathelectrotonus, first tetanus, then rest; after cathelectrotonus, momentary contraction. Now when cathelectrotonus follows upon anelectrotonus, as a comparison of figs. 3 & 4 will show, there must be discharge. And, further, when either electrotonic state is established, there must be that discharge which attends upon the closing of the circuit in any case; and hence the tetanus which happens when cathelectrotonus is made to follow anelectrotonus; for in addition to being acted upon by the salt, the muscles (the power of contracting is preserved in anelectrotonus) are at this time acted upon by the

two discharges which have been mentioned. Nor is it difficult to find a reason for the rest which follows the tetanus when cathelectrotonus is established, and the momentary contraction which happens when cathelectrotonus passes off. The rest which follows the tetanus under these circumstances is intelligible; for the cathelectrotonus may be supposed to do away with the power of responding to the action of the salt; and the momentary contraction which happens when the cathelectrotonus passes off is intelligible also; for, according to the premises, the cessation of the state of electrotonus implies the cessation of a state which counteracts that action of the salt which causes contraction. Moreover, it is intelligible enough that there should be tetanns after anelectrotonus, and momentary contraction only after cathelectrotonus, if the power of contracting be impaired in the one case and preserved in the other.

Nor is it otherwise with other experiments on electrotonus when care is taken to eliminate what is fallacious.

One and the same explanation, indeed, would seem to apply to the motor phenomena connected with anelectrotonus and cathelectrotonus, and to the motor phenomena connected with the inverse and direct currents; and this explanation is to be found, as it would seem, in the workings, not of the constant current, but of statical electricity.

The electrotonic variations in the conductibility of nerve detected by Professor von Bezold are reserved for future investigation.

April 15, 1869.

Lieut.-General SABINE, President, in the Chair.

The following communications were read:—

I. "On the Source of Free Hydrochloric Acid in the Gastric Juice." By Professor E. N. HORSFORD, Cambridge, U. S. A. Communicated by T. GRAHAM, F.R.S. Received January 18, 1869.

The long-disputed position of Prout that the gastric juice contains free hydrochloric acid, was at length established by C. Schmidt, who, in an absolute quantitative analysis of the juice, found about twice as much hydrochloric acid as was required to neutralize all the bases present. The prolonged discussion of this subject (now since 1823) has brought to light, through the researches of Lassaigne, Tiedemann and Gmelin, Berzelius, Blondlot, Claude Bernard, Schwann, and numerous others, the unmistakeable evidence of the presence of lactic acid and of acid phosphates in the gastric juice, which latter might or might not be due to the presence of lactic or hydrochloric acid. A point of special interest to the chemist and physiologist still remained, and was this: